'Good-Walker' + QCD dipoles = hard diffraction

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“Good-Walker” + QCD dipoles = Hard Diffraction[a]

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The Good-Walker mechanism for diffraction is shown to provide a link between total and diffractive structure functions and to be relevant for QCD calculations at small x_{Bj}. For Deep-Inelastic scattering on a small-size target (cf. an onium) the rôle of Good-Walker “diffractive eigenstates” is played by the QCD dipoles appearing in the $1/N_C$ limit of QCD. Hard diffraction is thus related to the QCD tripe-dipole vertex which has been recently identified (and calculated) as being a conformal invariant correlator and/or a closed-string amplitude. An extension to hard diffraction at HERA via k_T-factorisation of the proton vertices leads to interesting phenomenology.

1 The Good-Walker mechanism:

The Good-Walker mechanism [1] is known to provide a simple explanation of the link between two phenomena of high-energy (soft) scattering: *absorption* and *diffractive dissociation.* Our aim is to show that the mechanism can be used in QCD calculations of hard scattering at small x_{Bj} providing a simple connection between total and diffractive structure functions.

Let us consider the diffraction of a set of quantum states on a potential. *Absorption* describes the absorption of a given initial state due to the presence of inelastic channels. *Diffractive dissociation* is the observation that there exists transition between different such states, i.e. the transition matrix between initial and final diffractive states is not diagonal *a priori.* The Good-Walker mechanism [1] shows that the two phenomena are related through the fluctuations of the absorption factors. Let $<i|t|i>$ be the diffractive amplitude of a given initial state and consider a orthonormal diagonal basis $|m>$ of the transition matrix we can write :

$$<i|t|i>\equiv \sum_{m,n} <i|m><m|t|n><n|i>= \sum_{m} |<i|m>|^2<m|t|m>\Rightarrow \bar{t}, \tag{1}$$

where $\bar{t}$ is the average absorption factor. With the same notations, we may write diffraction-dissociation cross-sections in term of:

$$\sum_{m} <i|m><m|\ tt^{\dagger}\ |m><m|i> - <i|t|i><i|t^{\dagger}|i>\Rightarrow \overline{t\ t^{\dagger}} - \bar{t}\ \bar{t}^{*}. \tag{2}$$

[a] Invited talk at the DIS98 workshop, Brussels, April 1998.

From formulae (1,2) it becomes clear that the total contribution of diffractive dissociated states is related to the dispersion over absorptive factors. In the case of "soft" diffraction, these formulae relate total and diffractive cross-sections (actually for each impact parameter or partial wave). As we shall now see in "hard diffraction", it is a convenient way to relate total and diffractive structure functions and apply QCD calculations at small x_{Bj} to both observables. .

2 Hard diffraction off a *hard* target

In the past, there were interesting attempts [2] to identify the diagonal basis, or *diffractive eigenstates* with free partons. However, the applications to "soft" reactions prevent from the use of perturbative QCD calculations. On the other hand, partons (gluons) are not necessarily diffractive eigenstates in high-energy (small x_{Bj}) processes. In a recent approach[3,4], it was suggested to use the QCD dipole states as the diagonal basis of diffractive eigenstates in a hard scattering process, see fig.1. QCD dipole states appear [5] in the $1/N_C$ limit of QCD at high energy. The key observation is that the QCD dipole states interact purely elastically by the exchange of two gluons. On the other hand, the wave function of initial hard $q\bar{q}$ (onium) states in terms of interacting dipoles is known from QCD calculations in the infinite momentum frame [5]. Thus both the matrix elements $< m|t|m >$ and the coefficients $< i|m >$ in formulae (1,2) are determined in a suitable perturbative QCD framework.

In order to apply these properties to structure functions, let us consider the (theoretical) process of Deep Inelastic Scattering (DIS) on an onium target. In the same spirit as the Good-Walker derivation, two different components to hard diffraction happen to be relevant, the *elastic* and *inelastic* components corresponding to, respectively, the elastic and dissociative diffraction previously considered in soft processes. The virtual photon is represented by a well-defined [6] set of $q\bar{q}$ initial states which give rise to a collection of QCD interacting dipoles following [5]. The interaction of QCD dipoles from the photon with those from the onium give rise to a total structure function given by BFKL dynamics [7]. In the QCD dipole picture of the Good-Walker mechanism, it amounts to compute the distribution of absorptive factors as a function of the QCD dipoles, in practice as a function of their transverse sizes. Considering the inelastic component, one investigates the simultaneous interaction of *two* dipoles from the photon, see Fig.1a, to compute the dispersion of dipole sizes, and thus to generate a significant contribution to diffractive dissociation [3].

There is however a distinct component [6] which is analoguous to elastic diffraction in soft reactions. In this process, see Fig.1b, the photon $q\bar{q}$ states interact elastically with the target. The calculation of this component with QCD dipoles has been performed [4] and requires a novel quantum-mechanical aspect of QCD dipole calculations lying beyond the original Good-Walker description. Indeed, while the derivation has been made for the total cross-sections (eventually for each impact-parameter), it cannot be used for a given mass M of the diffracted state (neither for a given rapidity gap $\approx Y - \log M^2$ between the diffractive state and the target). In fact one cannot diagonalize the momentum operator and thus the mass of the diffractive state on the QCD dipole basis since [5] the QCD dipole basis requires kinematics to be described in a mixed representation using transverse coordinates and rapidity and not full momentum space. The correct implementation of this effect leads to interference terms in the final formulae [4].

Interestingly enough, diffractive processes happen to be related to some quite fundamental theoretical aspects of (resummed) perturbative QCD. The inelastic component has been shown [8] related to the $1 \rightarrow 2$ dipole transition vertex which, in turn, has a string theory interpretation [9] in terms of a closed string amplitude with 6 legs. It is possible to explicitely compute the triple-dipole vertex which appears to be quite large [10]. The computation of the same quantity can be done also in the framework of conformal field theory [11]. The stringy character of any $1 \rightarrow n$ dipole transition vertex [9] may lead to interesting theoretical developments. The other (elastic) component can also be exactly computed [12] with the help of a derivation [13] of the conformal coupling of a BFKL Pomeron to a general $q\bar{q}$ state.

3 Hard diffraction off a *soft* target

The application of the QCD dipole formalism to a more realistic target, e.g. a proton of the HERA ring, requires some care and simplifying assumptions. Indeed there exists large theoretical uncertainties in the use of perturbative QCD for hard scattering on a "soft" target. Let us briefly mention some of them. k_T-diffusion of the intermediate gluons [14] lead to a excursion inside the strong coupling domain of QCD near the proton vertex. More recently, a rather stringent upper limit in x_{Bj} due to the breaking of the Operator Product Expansion has been reported [15]. At the present conference were reported for the first time calculations of large next-to-leading BFKL corrections [16] which may invalidate predictions for proton structure functions. It is tempting to relate these theoretical objections to an old idea of Bjorken [17]. From the calculation of the photon wave function [6] it appears that the effective virtuality of the photon $q\bar{q}$ state is not Q^2 but $\hat{Q}^2 = z(1-z)Q^2$, where z is the momentum fraction of the photon beared by the quark. Thus, if the probability of z (or $1-z$) being small is sizeable, the effective virtuality may be of the same order of that of the target. In that case, the process may indeed be soft and thus not governed by perturbative calculations.

However, some arguments may be opposed to such a skepticism from both theoretical and phenomenological sides. It has been argued at this conference [18] that the same quantum state configurations which may invalidate a perturbative treatment of diffractive scattering may be washed out by the inclusive QCD resummation of structure functions. Moreover the "soft" part of the cross-section may be eaten out by the strong absorption expected from soft diffractive components. On a more phenomenological ground, there are hints that QCD dipole descriptions of proton structure functions do agree with present data using a small number of parameters describing the non-perturbative proton input [19]. Indeed, the k_T-factorization property of high-energy QCD [20] may be invoked to relate different structure functions of the proton [21]. Extending this factorization property to diffraction dissociation at the photon vertex, it is possible to find a convenient and economical (in terms of parameters) description of diffractive structure functions [22].

Acknowledgments

The material of this contribution is the result of a long term and stimulating collaboration with Andrzej Bialas, Henri Navelet and Christophe Royon. This work was supported in part by the EU Fourth Framework Programme 'Training and Mobility of Researchers', Network 'Quantum Chromodynamics and the Deep Structure of Elementary Particles', contract FMRX-CT98-0194 (DG 12 - MIHT).

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Figure 1: **the two diffractive components** (a) Inelastic (b) Elastic